ORIGINAL RESEARCH

VARIATION IN MEDIAL AND LATERAL GASTROCNEMIUS MUSCLE ACTIVITY WITH FOOT POSITION

Michael Cibulka, PT, DPT, MHS, OCS, FAPTA[1]
April Wenthe, DPT[1]
Zach Boyle, DPT, CSCS[1]
Dylan Callier, DPT[1]
Adam Schwerdt, DPT[1]
Deidra Jarman, DPT[1]
Michael J Strube, PhD[2]

ABSTRACT

Background: The gastrocnemius has two heads, medial gastrocnemius (MG) and lateral gastrocnemius (LG); little is known how they contract with different foot positions. The MG is more frequently strained than the LG; and gastrocnemius activation pattern altered by foot position may play a role in injury. Leg exercises often use a toe-in versus toe-out foot position to isolate one gastrocnemius head over another.

Purpose: The purpose of this study was to determine the electromyographic gastrocnemius muscle activity in the toe-out and toe-in foot positions during weight bearing and non-weight bearing activities. The hypothesis was that a toe-out foot position would elicit greater MG than LG activity; while the toe-in position would elicit greater activity in LG than MG in both weight bearing and non-weight bearing (NWB) positions.

Study Design: A cross-sectional study of young adults.

Methods: Thirty-three participants were recruited. Surface electrodes were placed on the bellies of the MG and LG. The gastrocnemius muscle was tested in toe-in and toe-out foot positions using two different tests: a standing heel-rise and resisted knee flexion while prone. Electromyographic activity was normalized against a MVIC during a heel raise with a neutral foot position. A 2x2x2 (Foot Position x Test Position x Muscle) ANOVA was used to determine if differences exist in activity between the MG and LG for toe-in versus toe-out standing and prone test positions.

Results: Significant test position main effect (F [1,32] = 86.9; p < .01), significant muscle main effect (F [1,32]= 5.5; p < .01), and significant foot position x muscle interaction (F [1,32] = 14.58; p < .01) were found. Post hoc tests showed differences between MG and LG in toe-out position (t = 3.10; p < .01) but not in the toe-in for both test positions (t = 1.27; p= 0.21).

Conclusions: With toe-out, the MG was more active than LG in standing and prone; no difference was noted between MG and LG in toe-in for either position.

Level of Evidence: Level 2

Key words: Electromyography, gastrocnemius, toe-in, toe-out

CORRESPONDING AUTHOR

Michael T. Cibulka
Maryville University
650 Maryville University Dr
St. Louis, MO 63141
E-mail: mcibulka@maryville.edu

[1] Maryville University, St. Louis, MO, USA
[2] Washington University, St. Louis, MO

INTRODUCTION

Physical therapists often see patients who have injuries related to the gastrocnemius muscle such as achilles tendinopathy, achilles tendon ruptures, and muscle strains. All of these conditions are associated with weakness of the gastrocnemius muscle.[1-4] Inexplicably gastrocnemius muscle strains occur almost exclusively in the MG muscle,[5-11] a condition called "tennis leg."[6,8,10] That the MG is found injured much more often than the LG suggests that the MG might have differences in activation patterns that make it more susceptible to injury than the LG muscle.

One possible explanation is that the MG and the LG muscles may have different patterns of activation. This idea originated from weightlifters that vary their foot positions in an attempt to emphasize contraction of one gastrocnemius head over the other. This same concept encouraged a study by Reimann et al who showed that when altering the lower extremities foot positions; the MG and LG have different amounts of muscle activity when performing a standing heel-raise.[12] Riemann et al showed that when pointing the toes-in, internally rotating the entire lower extremity, the LG was activated more than the MG during the concentric phase of a heel raise.[12] While when the entire lower extremity was externally rotated by pointing the toes out, the MG was activated more than the LG during both the eccentric and concentric phases of a heel rise.[12] So far no one has repeated this study, nor have they performed the same comparison during plantarflexion in a non-weight bearing position.

Different patterns of MG and LG activation with toeing-in versus toeing-out may have a neurological explanation for patterns of activity during gastrocnemius contraction. Toeing-in and toeing-out during gait influences the amount and direction of plantar pressure that develops on the plantar aspect of the foot.[13] Toeing-in puts more pressure laterally while toeing-out places more pressure medially on the plantar aspect of the foot.[13] Grimby has shown that plantar stimulation to the different parts of the sole of the foot creates different muscle activity in the leg.[14] Nurse et al demonstrated that muscular patterns in the lower extremity are altered when reducing the plantar pressure on the foot.[15] Thus, the activity of the MG and LG may be influenced by plantar pressure placed on the foot when weight bearing. Consequently, if plantar pressure variations were responsible for the pattern of activation, a non-weight bearing contraction would not likely create the same kind of pattern of MG and LG activation.

The impetus of this study came from clinical experience. We noted that performing gastrocnemius muscle strengthening exercises (plantarflexion with the knee extended) in a toe-out foot position led to faster rehabilitation times when treating those with medial gastrocnemius strains and medial insertional achilles tendonitis. The purpose of this study was to determine the electromyographic gastrocnemius muscle activity in the toe-out and toe-in foot positions during weight bearing and non-weight bearing activities. The hypothesis was that a toe-out foot position would elicit greater MG than LG activity; while the toe-in position would elicit greater activity in LG than MG in both weight bearing (WB) and non-weight bearing (NWB) positions.

METHODS

Recruitment of Participants

This study was a cross-sectional design where all data was acquired during one session. The Institutional Review Board at Maryville University approved this study. Participants included were a convenience sample from the surrounding St. Louis area. Recruitment was open to anyone from the ages of 18 to 65 years old. Participants were included if they were adults between 18-65 years old and could perform a 5/5 on a current MMT of the plantar flexors (tested by performing 25 heel raises on one leg of at least two inches in height), could follow simple instructions, and could perform all required positions (prone and standing) for at least fifteen minutes. The exclusion criterion included: a history of hip, knee, or ankle surgery in the prior year, history of lower extremity trauma in the prior year, lower extremity joint pain in the previous month, neuromuscular or musculoskeletal disorders that inhibit or impair movement, history of thrombophlebitis, and/or if the participant exhibited an adverse reaction to the electrode adhesive or gel. Prior to data collection all participants were informed of the experimental protocol and signed an informed consent. Participants then completed a questionnaire with demographic

information and reviewing the inclusion and exclusion criteria. Participants were given a randomized three-letter code to ensure participant confidentiality. All participants were unshod in this study. A simple coin toss was then used to determine which leg (to avoid "double dipping"; using both the left and right sides of a person as separate independent measures) the assessments would be performed on (*a priori* "heads" was designated the right leg, "tails" the left leg). All subsequent testing was performed on the designated leg. The participant was measured using the standing heel rise plantar flexor MMT, as described by Hislop et al.[16] Each participant was assessed for lower extremity alignment including the Craig-Ryder test and external tibial torsion. For the standing heel-raise MMT, participants performed the heel raises to the beat of a metronome. As used in previous research, the metronome was set at 60 beats/minute (one heel raise per two seconds).[17-19] If the participant could complete 25-heel rises[17] they were included in the study.

EMG Setup

To determine electrode placement for the MG and LG, a prone resisted plantar flexion contraction was elicited, the muscles were palpated, and the electrodes were placed over the most prominent section of each corresponding muscle belly.[19] The electrode placement areas were shaved as needed and the skin was abraded with an alcohol swab. The recording electrodes were placed in parallel with the muscle fibers. Two additional ground electrodes were placed on the tibial tuberosity and the fibular head to decrease EMG artifact. The MG and LG were recorded using individual disposable, Ag/AgCl sEMG Norotrode 20 bi-polar surface electrodes (Myotronics Inc., Kent, WA) with 10 mm pickup diameter with 22mm interspacing between the bi-polar electrodes and the Motion Lab Systems MA420 bi-polar preamplifiers. Electrode placement was confirmed by assessing EMG that were tested prior to data collection using unilateral standing plantar flexion contractions. Electrodes were firmly secured with 2 cm wide tape. The gain was adjusted as needed before formal data collection.

All EMG signals were recorded for the MG and LG using an MA-300 EMG system connected to a laptop computer via a DI-720 USB Data Acquisition System (Motion Lab Systems Inc., Baton Rouge, LA). The EMG system signal bandwidth was 10 Hz – 2 kHz, – 3 dB limited to 10–350 Hz, using the low-pass Bessel filter in the MA300. All EMG data were sampled at 1,876 samples per second per channel, using WinDaq Data Acquisition Software (DATAQ Instruments Inc., Akron, OH).

Determination of Maximal Voluntary Contraction

To determine the maximum voluntary isometric contraction (MVIC) from each participant's MG and LG a stationary barbell was used for the participant to push up into during isometric plantarflexion when standing using a set up similar to Hebert-Losier et al.[20] EMG values were collected during the performance of two MVICs heel rises in a unipedal standing position. A previous study showed that the standing weight bearing position is just as effective as the NWB position when attempting to elicit a maximal contraction from the gastrocnemius muscle.[20] Two trials of MVIC testing were conducted with a two-minute rest period between tests. The length of each test was approximately five seconds with two seconds of a ramped increasing effort and three seconds of a sustained maximum isometric contraction. The two MVIC trials were then averaged to establish the MVIC score. Testing for MVIC was performed in a modified squat rack so that the barbell was firmly secured so that it would remain stationary. Participants stood comfortably and the height of the barbell was adjusted so as to rest on the posterior deltoids and upper thoracic spine region (e.g. as in performing a normal squat) of the standing participant with the knees extended at 0°. Padding was added as needed to the bar to maximize patient comfort while pushing up maximally. Participants positioned themselves under the stationary barbell standing unilaterally on the test leg in a comfortable weight bearing foot position and when instructed plantar flexed isometrically with maximal effort. The ankle was positioned midway between their neutral and full plantarflexion. The previously described position with the knee at 0° and in weight bearing has been found to most frequently elicit a MVIC of the gastrocnemius muscle.[18,21] Participants were allowed to familiarize themselves with the set up and were given two minutes to recover prior to

Figure 1. *Standing heel rise position (Toe-in position).*

formal testing. For all weight-bearing tests participants were instructed to isometrically "try to push upwards on the bar as hard as you can" and "keep your knee straight." To obtain the MVIC data for each participant, the data was filtered (to remove DC values) and mathematically squared creating data values that were only positive. The square root of these mean values were taken from the data window of the last three seconds of the five-second reading of the unilateral isometric maximum plantar flexion contractions and were used in the normalization process.

DESCRIPTION OF TEST POSITIONS

WB Test Position
The standing WB position was identical to the method used to determine MVIC with the only difference being the performance of the test using two positional variations: a position of maximal in-toeing and one of maximal out-toeing of the foot. The toe-in (Figure 1) and toe-out positions were accomplished by having the participant fully rotate the entire lower extremity in or out. The instructions

during testing were identical to testing for MVIC as described previously, and each contraction was held for five seconds. Three contractions per each test variation were used to gather EMG data from the MG and LG muscles.

NWB Test Position
A NWB position was used to test the gastrocnemius muscle to determine if the same pattern of activity resulted with the toe-in and toe-out positions using a resisted test of knee flexion due to the role of the gastrocnemius as a secondary flexor of the knee. Although the gastrocnemius is not a strong knee flexor this action was chosen to see if the same pattern of muscle activity in the MG and LG occurred during knee flexion and without applying pressure to the plantar aspect of the foot. Results of a previous study have already shown that the MG and LG muscles have less muscle activity in the NWB position compared to WB [20] therefore the authors chose to investigate gastrocnemius activity during a different action (knee flexion). For the NWB (prone) position, participants were instructed to "bend the knee," "pull as hard as possible," or "keep pulling," while the examiner applied a "break" force approximately 8 cm proximal to the malleoli in the direction of knee extension (Figure 2) for five seconds. Participants were allowed to hold onto the treatment table as needed for stabilization during the muscle tests. These verbal instructions were standardized for each participant in order to encourage maximum contraction. Three contractions per each test position were performed to gather EMG data from the MG and LG muscles.

EMG Capture and Normalization
Data were recorded during all positions and rotational variations (as described above) with Motion Lab Electromyography (MA 300) using a Gateway Laptop (Model QA1) and stored on a password protected USB device in Motion Lab Systems C3D files using EMG Analysis and Graphing software (Motion Lab Systems Inc., Baton Rouge, LA). The root-mean-square (rms) amplitudes (expressed in μv) from the MG and LG during all test conditions were determined by taking the EMG signals from the last three seconds of the five-second isometric contractions for each participant. The data from each of the three
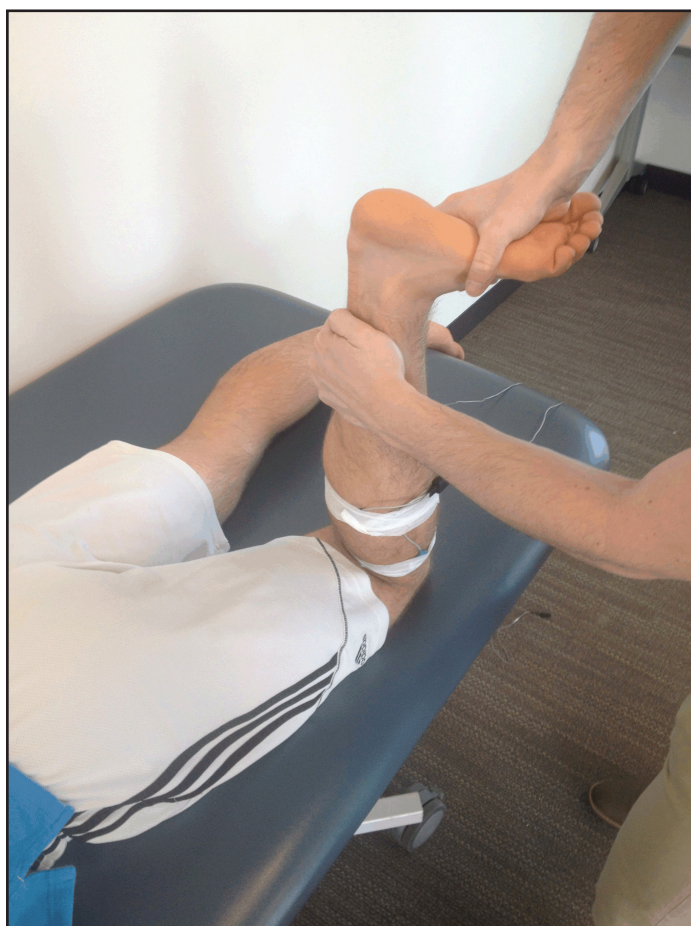
Figure 2. *Resisted prone knee flexion (Toe-out position).*

trials was averaged for all data collected from WB and NWB tests. The EMG rms amplitudes from test conditions were normalized using the previously established values for MVIC for each muscle group.

Data Analysis
The statistical package R (R: A Language and Environment for Statistical Computing, R Core Team, R Foundation for Statistical Computing, Vienna, Austria) was used for data analysis. The outcome data was the mean peak normalized muscle activity for the MG and LG in each of the positions and variations. Data are presented as percentages of MVIC with means and standard deviations ($\pm$SD). The normalized EMG data was also analyzed using the intraclass correlation coefficient statistic (ICCs 3,1) to determine test-retest reliability for the prone testing position.

A 2x2x2 (Foot Position x Test Position x Muscle) repeated measures of analysis of variance (ANOVA) was used to analyze the data to determine if differences exist in Muscle activity between the MG and LG when comparing toe-in versus toe-out foot positions while in the standing and prone test positions. A Bonferroni correction was applied on the post hoc tests to prevent family wise error inflation.

RESULTS
The group of participants (20 females, 13 males) had a mean age of 21.7 years (range: 19-25), weight: 72.6 kg (range: 52-113.4 kg.), height: 172.6 cm (range: 157.5-193.0 cm). All of the participants were right leg dominant except one, which was determined by asking them with which leg they would normally kick a ball. Also all participants were healthy students that were active either in sports or recreational activities. Lower extremity alignment measures for mean femoral anteversion was 10.4° (range: -1 to 19°) and the mean tibial torsion was 5.1° (range: -11 to 15°).

Intra-rater reliability was high for the NWB normalized EMG data in for the MG for toe-in (ICC = .91) for MG toe-out (ICC = .95), for LG toe-in (ICC = .87) and LG toe-out (ICC = .85). The standard error of the measure (SEM) for the normalized muscle activity for the LG = 6.7% while the MG = 4.7%. The reliability for standing normalized EMG was not assessed because of concerns over fatigue of the gastrocnemius muscle.

The MG achieved 41.3% MVIC in the prone (NWB) test position with toe-in while the LG achieved 37.8%, the MG had 43.5% MVIC while the LG had 32.6% in the toe-out position. In the (WB) standing position toe-in the MG had 75.8% MVIC while the LG had 70.7%, with toe-out the MG had 79.2% MVIC while the LG had 68.9%. Figure 3 and 4 show all of the means and standard errors for each test position. EMG activation was always greater for the MG than the LG during all positions and rotational variations, but the differences were not statistically significant.

No differences were found between the normalized MG and LG outputs (mean: MG = 4.93 µv; LG = 5.02 µv; t= -1.60; p = .94) when performing a heel rise while standing with the foot in a neutral position (toes pointed straight forward) during the MVIC testing. However, a significant test position main effect (F [1,32] = 86.9; p < .01), a significant muscle main
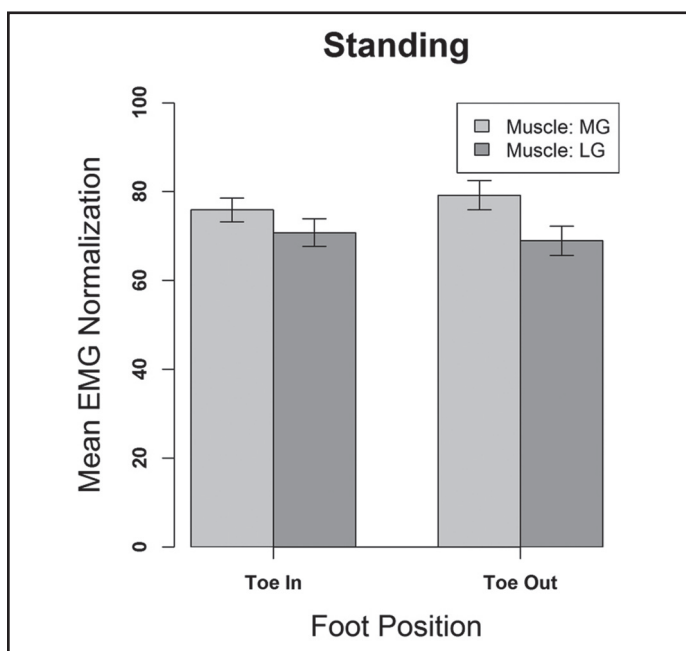
Figure 3. *Mean EMG for Toe-in and Toe-out Positions for Standing Heel Rise.*
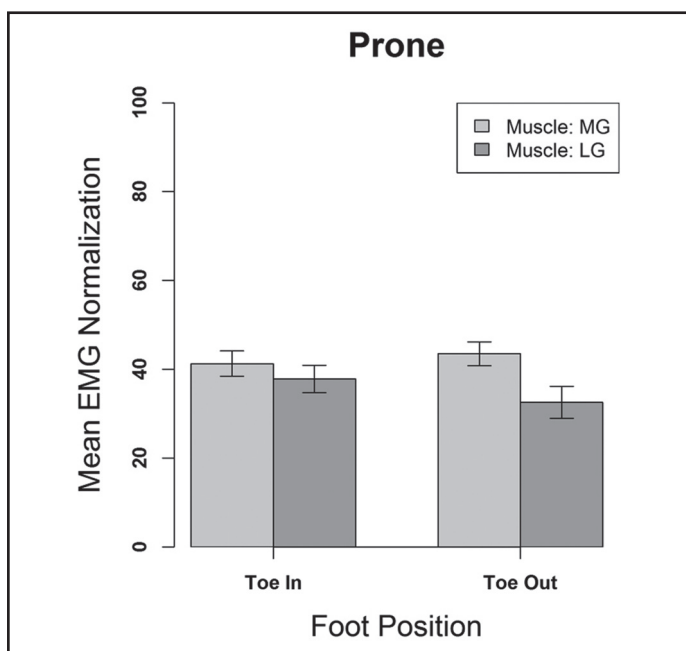

Figure 4. *Mean EMG for Toe-in and Toe-out Positions for Resisted Knee Flexion while Prone.*

effect (F [1,32] = 5.50; p < .01), and a foot position x muscle interaction (F [1,32] = 14.58; p < .01) were found. Post hoc tests showed a significant difference between MG and LG activation in the toe-out position (t = 3.10; p < .002), with greater MG activation, but not in the toe-in positions for both prone and standing test positions (t = 1.27; p = 0.21).

DISCUSSION

The results of this study shows that differences in EMG activation between the MG and LG exist when altering foot position during a weight bearing (standing heel rise) and non-weight bearing (resisting knee flexion while lying prone) activities. The MG was significantly more active than the LG in the toe-out positions in both the weight bearing and non-weight bearing positions, which did not support the hypothesis that plantar pressure, during weight bearing, would have an effect on the pattern of MG-LG activity. The results from this study support the hypothesis that the toe-out position elicited more MG than LG activity. These results also agree with previous research by Riemann et al who showed that that during WB the MG was more active than the LG during both the concentric and eccentric phase of plantarflexion in a toe-out position.[12] No differences were noted between the MG and LG when in the toe-in position for either weight bearing (standing) or non-weight bearing (prone) test positions thus the current results did not support the hypothesis that the toe-in position would elicit more LG than MG.

Riemann et al reported results that were similar to this study in that they did not find a difference between MG and LG during toe-in during the eccentric phase of a heel raise, however they did show that the LG was activated more than the MG during a concentric heel raise.[12] In the current study only isometric contractions were performed. Also in the current study the MG always produced greater EMG activation than the LG during both weight bearing and non-weight bearing test positions and with toe-in and with toe-out foot positions (Table 1). Fiebert et al found similar results with integrated muscle activity during maximal plantarflexion; the activity of the MG was always greater than the LG, but not significantly. Interestingly the muscle activity level of the MG changed very little when comparing toe-in to toe-out for both the non-weight bearing (prone) and weight bearing (standing) positions, however the LG was significantly different between toe-in and toe-out but only for the prone position. Perhaps this pattern of activation is an integrated ontogenic response pattern developed in our central nervous system.

Herbert-Losier et al found that the gastrocnemius muscles (MG and LG) displayed much less activity

Table 1. *MVIC Normalized Data in Prone Test Positions (%) (N=33)*				
	Toe-In		**Toe-Out**	
Muscle	**Mean (sd)**	**Range**	**Mean (sd)**	**Range**
MG	41.29 ± 16.3	7.37-64.4	43.53 ± 15.4	14.2-71.3
LG	37.83 ± 17.7	3.06-76.2	32.58 ± 20.7	3.4-90.5

Table 2. *MVIC Normalized Data for Standing Heel Rises (%) (N=33)*				
	Toe-In		**Toe-out**	
Muscle	**MVIC (sd)**	**Range**	**MVIC (sd)**	**Range**
MG	75.8 ± 15.4	37.95-107.9	79.2 ± 18.8	39.39-143.6
LG	70.7 ± 17.9	43.86-117.8	68.9 ± 18.8	32.12-126.7

when the knee was flexed to 90º when compared to 0º degrees during NWB testing.[18] This is consistent with Fiebert et al who found that when the gastrocnemius muscle was placed at different muscle lengths muscle activity was lower when the muscles were shortened and greater when they were lengthened.[22] Fiebert et al found that as the knee flexes from full extension to 90º flexion the activation of the MG and LG significantly declines,[22] the muscle shortening that is described by the properties of the length-tension curve. The results of the present study also demonstrated that the activity of the MG and LG while prone with the knee flexed 90º was considerably less than when standing where the knee is in full extension.

Rotating the lower extremity internally or externally by toe-in or out may alter the biomechanics of the MG and LG muscles. Riemann et al hypothesizes that rotating the hip may change the line of force projected through the ankle joint to shift laterally during IR and medially with ER.[12] Riemann et al also suggests that IR and ER of the lower extremity may alter the architectural features of the MG and LG such as the line of action, angle of pennation, and fascicle lengths influencing the force-generating capabilities of the MG and LG.[12] The MG moment arm is considered an external rotator of the tibia while the LG an internal rotator of the tibia on the femur.[23] Thus an isometric contraction is needed to "hold" the tibia in external rotation (out-toeing) would likely produce more MG activity with an isometric contraction to "hold" the tibia in internally rotated (in-toeing) would produce more LG activity. Further studies are needed to confirm these patterns of activation.

Both static tibial torsion and hip anteversion were measured using the Craig-Ryder test to examine the ranges of toe-in and toe-out and to note any outliers that could have affected the results. A caveat is that toe-in or toe-out positions were not standardized. Participants were asked to maximally internally or externally rotate their legs during the toe-in and toe-out heel raises, without standardizing the degree of leg rotation. Thus we do not know if a particular amount of internal and external rotation would modify EMG activation. Also, we did not measure reliability and validity of the Craig-Ryder test or the Thigh-Foot Angle tests; this could be a source of error. Future research that looks at those who have significantly greater toe-in or toe-out would be interesting.

A number of other factors may have influenced the generalizability these results. First, the participants that volunteered to participate in this study consisted of young college-aged men and women (19-25

years old). It is difficult to determine if comparable results would be found with other populations, such as older adults. When using surface electrodes to measure electrical activity of a muscle sources of possible error include skin impedance and cross talk between muscles. To decrease skin impedance, the skin was abraded with an alcohol swab. However, electrical resistance (ohms) was not assessed to measure the amount of impedance. Cross talk is always a limitation with surface electrodes. Ekstrom et al suggest that surface EMG is appropriate for superficial muscles,[24] the gastrocnemius muscles are superficial and easily located. Perhaps a future study with indwelling needle electrodes could be performed.

CONCLUSIONS

A toed-out foot position creates greater muscle activity in the MG than the LG when standing and performing a heel raise and when resisting knee flexion while lying prone. No differences were noted between MG and LG in the toe-in foot position between the two test positions (WB and NWB). However, the EMG activation was always greater for the MG than the LG during all positions and rotational variations, but the differences were not statistically significant. The muscle activity of the MG and the LG during contraction of the gastrocnemius muscle were also consistent for both weight bearing versus non-weight bearing suggesting that a pattern of muscle activation that may be an integrated pattern established in our central nervous system.

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